Human Spaceflight Capabilities

Flexible Ultrasound System for Quantitative Diagnosis and Therapeutic Ultrasound

Completed Technology Project (2015 - 2017)

Project Introduction

This project provides funding to integrate the technology produced by the National Space Biomedical Research Institute (NSBRI) project entitled "Portable Quantitative Ultrasound with DXA/QCT and FEA Integration for Human Longitudinal Critical Bone Quality Assessment (SMST03401)" with NASA's flexible ultrasound system (FUS).

Skeletal complications, i.e., osteoporosis, induced by microgravity during extended space missions represent a key astronaut health problem. Lack of on-board diagnosis has increased significant risk in astronauts' bone loss during long term space flight. Early diagnosis of such disorders can lead to prompt and optimized treatment that will dramatically reduce the risk of fracture and longitudinal monitoring microgravity and countermeasure effects. Advents in quantitative ultrasound (QUS) techniques provide a method for characterizing the material properties of bone in a manner for predicting both BMD (bone mineral density) and mechanical strength. We have developed a scanning confocal acoustic navigation (SCAN) system capable of generating noninvasive ultrasound images at the site of interest.

To improve the efficiency of the scan in extreme environments, such as space missions, the goal of this study is to develop a 2-D array ultrasound transducer including a pair of 32x32 elements using program/electronic control to generate co-focal ultrasound energy and perform scan in the region of interest for extracting density and quality information bone. This 2-D array setting and scan controlled by programming can conduct the scan at targeted skeletal sites within a few seconds, provide reduced physical footprint, reduced weight, and ease of use. The transducers will be integrated with a GE flexible ultrasound system (FUS). To utilize an electronic scan device, we design the specs for the array system, simulate a 2-D spatial sweep mode, designing of MUX system for connecting FUS and the transducers, and hardware of the transducer. A 2-D array therapeutic portable device and system is also designed and developed, which is currently used in an animal study, and scheduled for a human study.

Technical Summary

Non-invasive assessment of trabecular bone strength and density is extremely important in predicting the risk of fracture in space and ground operation. To overcome the current hurdles such as soft tissue and cortical shell interference, improving the quality of QUS and applying the technology for future clinical applications, a 2-D array transducer system is developed for improving the SCAN efficiency by reducing scan time and performing program controlled electronic scan in the deep tissue. The transducers is designed for integration with the GE flexible ultrasound system (FUS). This phase of the development of array SCAN system is focused on several main areas: 1) acoustic field simulation for scanning angle and spatial region using 32x32 array, 2) design of Maximal element count possible with 192 channel

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constraint in the GE FUS, 3) 2-D array transducer design and manufacture, 4) MUX system design for array trigger and receiving signal control, 5) integration with GE FUS cabling system, and 6) 2-D therapeutic system design and validation. The transducers will be integrated into the FUS to provide portable rapid array SCAN system combined with imaging capability, and to provide low-intensity ultrasound treatment for bone fracture and low bone mass, which will ultimately provide a portable, noninvasive device for guided imaging monitoring and therapeutic for bone diseases in space.

Earth Applications: Skeletal decay complications are major health problems on Earth, i.e., osteoporosis, and delayed healing of fractures. Development of a low mass, compact, noninvasive diagnostic and treatment technology, i.e., using ultrasound, will have a great potential to prevent and treat bone fracture. Our principal goal is to develop a portable quantitative ultrasound system with therapeutic capability, not only for determination of bone's physical properties, but also for predicting subtle changes of bone during extended flights and diseased condition, which will impact both diagnosis and noninvasive treatment for musculoskeletal disorders. Use of a desktop based non-ionizing bone assessment device has great clinical applications as an in-office quantitative assessment of fracture risk in the general and at-risk populations.

Key findings and milestones

To overcome the current hurdles such as soft tissue and cortical shell interference, improving the quality of QUS and applying the technology for future clinical applications, a 2-D array transducer system is developed for improving the SCAN efficiency by reducing scan time and performing program controlled electronic scan in the deep tissue. This phase of the development of array SCAN system has achieved several milestones. 1) To develop an acoustic field simulation for scanning angle and spatial region using 32x32 array, which provides fundamental analysis for the design of the array transducers and associated specs. 2) To design the 32x32 sensor layout with maximal element count possible with total of 96 channels (determined by the GE FUS system). 3) To design and manufacture the 2-D array transducer at a transducer vendor (Blatek, Inc.). 4) To design schematic layout, and PCB layout for a MUX system for array trigger and receiving signal control, for converting 32x32 total lines to reduced 96 channels. 5) To interface GE cable coupling system and integration with GE FUS cabling system. 6) To develop and validate a 2-D array therapeutic system for low-intensity ultrasound therapeutic treatment for bone loss and fracture. The team is able to closely work with transducer vendor, Blatek, NASA Glenn Center, and GE Global Research Center for the 2-D array system and integration with FUS.

Anticipated Benefits

Organizational Responsibility

Responsible Mission Directorate:

Space Operations Mission Directorate (SOMD)

Lead Organization:

National Space Biomedical Research Institute (NSBRI)

Responsible Program:

Human Spaceflight Capabilities

Project Management

Program Director:

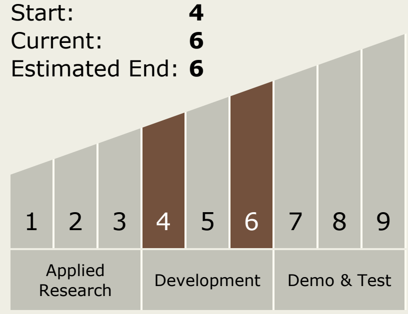
David K Baumann

Principal Investigator:

Yi-xian Qin

Technology Maturity (TRL)

Start: **4**
Current: **6**
Estimated End: **6**



Technology Areas

Primary:

Continued on following page.

Musculoskeletal decay due to a microgravity environment has greatly impacted the nation's civil space missions and ground operations. Such musculoskeletal complications are also major health problems on Earth, i.e., osteoporosis, and the delayed healing of fractures. About 13 to 18 percent of women aged 50 years and older and 3 to 6 percent of men aged 50 years and older have osteoporosis in the US alone. One-third of women over 65 will have vertebral fractures and 90% of women aged 75 and older have radiographic evidence of osteoporosis. Thus, approximately a total of 28 million people suffer from osteoporosis in the United States, with an estimated annual direct cost of over $30 billion to national health programs. Hence, an early diagnosis that can predict fracture risk and result in prompt treatment is extremely important. Ultrasound has also demonstrated its therapeutic potentials to accelerate fracture healing. The objectives of this study are focused on developing a combined diagnostic and treatment ultrasound technology for early prediction of bone disorder and guided acceleration of fracture healing, using SCAN imaging and low-intensity pulse ultrasound. Development of a low mass, compact, noninvasive diagnostic and treatment modality will have great impacts as early diagnostic to prevent bone loss and accelerate fracture healing. This research will address critical questions in the Bioastronauts Roadmap related to non-invasive assessment of the acceleration of age-related osteoporosis and the monitoring of fractures and impaired fracture healing. The results have demonstrated the feasibility and efficacy of SCAN for assessing bone's quality in bone. We have been able to demonstrate that the bone quality is predictable via non-invasive scanning ultrasound imaging in the region of interests (ROI), and to demonstrate the strong correlation between SCAN determined data and QCT (quantitative computed tomography) identified BMD, structural index, and mechanical modulus. These data have provided a foundation for further development of the technology and the clinical application in this research.

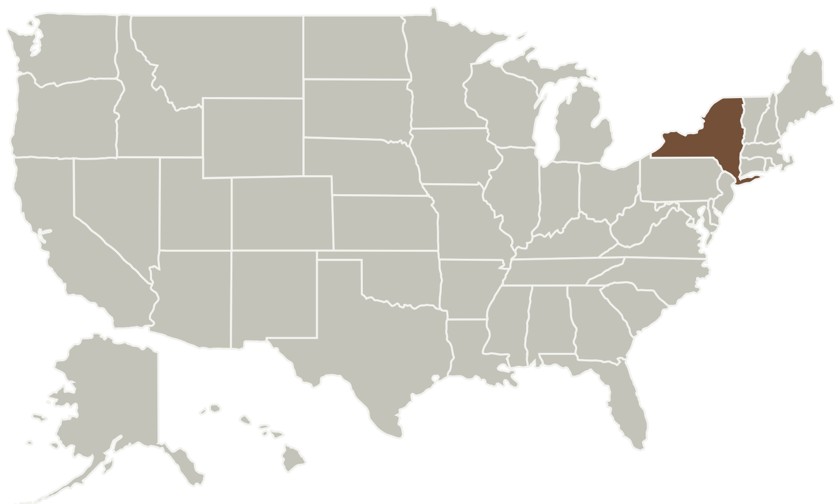
Technology Areas *(cont.)*

- TX06 Human Health, Life Support, and Habitation Systems
  - └ TX06.3 Human Health and Performance
    - └ TX06.3.6 Long Duration Health

Target Destinations

The Moon, Mars

Primary U.S. Work Locations and Key Partners



Organizations Performing Work	Role	Type	Location
National Space Biomedical Research Institute(NSBRI)	Lead Organization	Industry	Houston, Texas
State University of New York at New Paltz	Supporting Organization	Academia	New Paltz, New York

Primary U.S. Work Locations
New York

Project Transitions

May 2015: Project Start

May 2017: Closed out

Closeout Summary: Musculoskeletal complications induced by age-related diseases like osteoporosis and in long-term dis use osteopenia, such as with a lack of gravity during extended space missions and long-term bed rest, represent a key heal th problem. Such a skeletal disorder changes both the structural and strength properties of bone, and the latter plays a criti c role in ultimately leading to fracture. Early diagnosis of progressive bone loss or poor bone quality would allow prompt tre atment and thus will dramatically reduce the risk of bone fracture. While most of the osteoporotic fractures occur in cancell ous bone, non-invasive assessment of trabecular strength and stiffness is extremely important in evaluating bone quality. U ltrasound has also been shown therapeutic potentials to accelerate fracture healing. We are able to develop a SCAN system combined with therapeutic ultrasound capable of generating acoustic images at the regions of interest for identifying the str ength of trabecular bone, in which the system is capable of generating non-invasive, high-resolution ultrasound attenuation and velocity maps of bone, and thus determining the relationship between ultrasonic specific parameters and bone mineral density, and bone strength and bone's physical properties (i.e., stiffness and modulus). Using the 2-D array ultrasound tran sducers can generate confocal ultrasound beam in the region of interests electronically by the programming. The scan time can be significantly reduced. The ultrasound resolution and sensitivity are significantly improved by its configuration, compa red to the existing technology. The issue of free water in microgravity has been solved by the development of a pair of arra y transducers which would also allow for the replacement of water with a more ideal liquid such as mineral oil. The transduc ers can be integrated on to the FUS.

Stories

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/45089)

Articles in Peer-reviewed Journals
(https://techport.nasa.gov/file/45091)

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(https://techport.nasa.gov/file/45090)

Project Website:

https://taskbook.nasaprs.com